ME-87-03

Bridge Bearing Performance in Ontario

Ontario

Ministry of Transportation and Communications

Research and Development Branch

ME-87-03

Bridge Bearing Performance in Ontario

D.G. Manning
Principal Research Engineer
Materials Research Office
Research and Development Branch, MTC

K.G. Bassi
Head, Design Section
Structural Office, MTC

Published by
The Research and Development Branch
Ontario Ministry of Transportation and Communications
Hon. Ed Fulton, Minister
D.G. Hobbs, Deputy Minister

Published without prejudice as to the application of the findings. Crown copyright reserved; however, this document may be reproduced for non-commercial purposes with attribution to the Ministry.

For additional copies, write:
The Editor, Technical Publications
Room 320, Central Building
1201 Wilson Avenue
Downsview, Ontario
Canada M3M 1J8

Telephone: (416) 248-7226
CNCP Dialcom: 21:MIN006

January 1987

Technical Report Documentation Page

Bridge Bearing Performance in Ontario

Authors:	D.G. Manning, Principal Research Engineer, Materials Research Office K.G. Bassi, Head of Design, Structural Office
MTC No.:	ME-87-03
Published by:	The Research and Development Branch Ontario Ministry of Transportation and Communications
Participating Agencies/-Client:	
Abstract:	This paper reviews the historical development of the use of bearings in Ontario, and the current design requirements contained in the Ontario Highway Bridge Design Code and the Ministry's bearing specifications. Numerous instances of unsatisfactory bearing performance, especially of proprietary rotational and sliding bearings, are described. Examples are given of unsatisfactory performance resulting from poor bridge design practices, improper bearing design, poor manufacturing procedures, and incorrect installation. In all cases, the action which has been taken to prevent recurrence of the deficient performance is presented. The basic philosophy in design is to use the minimum number of bearings consistent with the articulation of the structure. The severity of the service environment has been recognized, with the result that a high degree of corrosion protection is specified and provision is made for bearing replacement. All bearings are required to have capacity for rotation about all three axes, which means that rockers, rollers, sliding plates, and cylindrical bearings are no longer used. The paper also describes the contractual relationships involved in the supply of highway bridge bearings and concludes that, although a performance specification and guarantee would be desirable, such an approach is not practical.
Comments:	Presented at the Second World Congress on Joints and Bearings, San Antonio, Texas, September 28 - October 2, 1986.
Key words:	articulation, bearings, bridges, durability, rockers, rollers, sliding plates
Distribution:	MTC Districts and Regions, Engineering Materials Office, Structural Office, Municipal Engineers
Copyright Status:	Crown copyright

Table of Contents

Introduction	1
Design Requirements	2
Bearing Performance	3
Acceptance of Bearings	5
Conclusions	8
References	8

List of Tables and Figures

Tables

1/ Summary of Deficiencies Observed in Pot Bearings and TFE Sliding Surfaces 10

2/ Physical Properties of Natural Rubber Disc 15

3/ Physical Properties of TFE Elements 15

Figures

1/ Site 32-008, Dartmoor Bridge, Conc. 2, Dalton Twp., Victoria County 16

2/ Site 03-042, Maitland Avenue U.P., Hwy 417 16

3/ Site 29-172, Portage du Fort Interprovincial Bridge, Hwy 653 17

4/ Site 15-064, Mississippi River Bridge, Hwy 7 17

5/ Site 11-239, Trent River Bridge, Trenton 18

6/ Site 11-239, Trent River Bridge, Trenton 18

7/ Site 03-270, Boundary Road U.P., Hwy 417 19

8/ Site 03-303, Eastbound O.P., Hwys QEW/417 I.C. 19

9/ Site 37-812, Bridge No. 27, Hwys 401/27 I.C. 20

10/ Site 03-263, Seventh Line U.P., Hwy 417 20

11/ Site 28-028, Norris Whitney Bridge, Hwy 62 21

12/ Site 37-812, Bridge No. 27, Hwys 401/27 I.C. 21

13/ Site 27-207, Vars Road U.P., Hwy 417 22

14/ Site 27-210, South Nation River Bridge, Hwy 417 22

15/ Site 27-210, South Nation River Bridge, Hwy 417 23

David G. Manning is Head, Materials Research, Ontario Ministry of Transportation and Communications, Downsview, Ontario, Canada. Dr. Manning was chairman of the technical committee responsible for the section "Bearings and Deck Joints" in the first and second editions of the Ontario Highway Bridge Design Code.

Kris G. Bassi is Head, Bridge Design, Ontario Ministry of Transportation and Communications, Downsview, Ontario, Canada. He is chairman of the Ministry's Bearing Committee and is a member of the Ontario Highway Bridge Design Code Committee.

INTRODUCTION

Until the mid 1950's, the bearings used in Ontario's bridges consisted of simple mechanical devices and included sliding plates, rollers, and rockers. Each of these types had inherent deficiencies: the sliding plates seized, small diameter rollers had a tendency to flatten, roller nests did not share the load equally, and rockers were prone to tilt. Steel-laminated elastomeric bearings were introduced in 1957 and have been successfully used for bridges with translations up to about $\pm$75 mm.

In 1962, during the design of structures for a complex freeway interchange, the advantages of supporting torsionally stiff bridge superstructures on slender, single round columns as a means of overcoming serious space restrictions became evident. The newly developed pot bearings located on the top of columns could support the heavy loads and accommodate the required rotations with a very slight shift in the axial load. As a result, the number and the sizes of the columns could be kept to a minimum. Initially, only pot bearings were used but as spherical and disc bearings became available in later years, they were accepted as alternatives to the pot bearings where equivalent load and movement capacity could be provided.

The past thirty years have seen the change from simple, robust devices unsuited to most modern bridges to more complex bearings incorporating several components, the design and manufacture of which are critical to the satisfactory performance of the bearing. As might be expected, the introduction of sophisticated, precision engineered components to the hostile bridge environment where corrosion, large construction tolerances, and unanticipated movements are common, has not been easy. Indeed, as with the corrosion of embedded reinforcement, underestimating the severity of the highway bridge environment has been a significant factor contributing to poor bearing performance. Deck joints frequently leak; debris, usually moist

and salt-laden sand, accumulates on the bearing seats; design details are often deficient; ventilation is poor and preventive maintenance usually non-existent. Add to this the facts that most bridge designers know little about bearings, that products are usually selected from manufacturer's catalogs and that, under most bidding procedures, the designer has little influence over the particular product supplied, and it is not surprising that bearing problems have occurred. This paper describes the experiences of bearing performance in Ontario and what action has been taken to try and prevent similar problems in the future.

DESIGN REQUIREMENTS

Prior to 1979, bridges in Ontario were designed to the AASHTO specifications (1) with a few minor modifications. The Ministry used its own specification for elastomeric bearings which allowed higher stresses than were permitted by the equivalent AASHTO specification. The requirements for other types of bearings were contained in a brief special provision which was used for many years but never formalized in a standard specification. It is somewhat ironic that the bearings with the highest load and greatest movement capacities had the fewest requirements!

In 1976, the decision was made to write the Ontario Highway Bridge Design Code (OHBDC) and the first edition was published in 1979 (2). The Code was written in a limit states format and was based on a new design load (3). The chapter on bearings and deck joints required the development of new material within the constraints of a very short time frame, compatibility with other parts of the Code, and the capability of immediate implementation. The result was that the clauses dealing with bearings were largely a reflection of Ministry practice at that time and the embodiment of the appropriate sections of other Ministry documents. Although requirements for ultimate limit states were contained in the Code, it was not possible to obtain data from bearing manufacturers or to define adequately the test conditions under which such data should be collected. Consequently, it was decided that bearings satisfying the Code provisions at serviceability limit states would also be deemed to satisfy the requirements for ultimate limit states.

Despite its limitations, the first edition of the OHBDC established two important principles which have had a significant impact on bridge design. It was recognized that bearings are an expensive and potentially troublesome component of bridges and the basic philosophy was adopted of using the minimum number of bearings consistent with the articulation of the structure. Secondly, it was recognized that bearings, like any other mechanical component, have a limited life and the structure must be designed to permit replacement of the bearings. In addition, the Ministry also developed design details such as sloping bearing seats which reduced the potent-

ial for exposure to surface run-off, improved its inspection practices and introduced preventive maintenance practices which include the removal of debris from around bearings.

A second edition of the Code was published in 1983 (4). While the limitations on the ultimate limit state provisions still applied, the second edition included many new requirements for bearings and especially for TFE sliding surfaces. These new clauses were based, in part, on draft versions of BS 5400 (5) and other European literature. The publication of the second edition of the Code provided the impetus for the development of comprehensive specifications for translational and rotational bearings (other than unconfined elastomeric bearings which were the subject of a separate specification). These specifications, one dealing with materials (6) and the other with installation (7), have been written to complement the OHBDC, but also address deficiencies which have been recognized in bearing performance in recent years. Specific requirements will be discussed in detail in the body of this paper.

Since the advent of elastomeric bearings and of pot bearings and related devices, the Ministry has used proprietary bearings. It is neither practical nor desirable for bridge designers to produce individual designs for bearings and considerable benefits in both economy and performance can be expected from using standard, commercial products. Consequently, a bearing meeting the designer's requirements is chosen from a manufacturer's catalog. The class of bearing, load and movement requirements, together with any other specific requirements are shown on the plans. The overall height of the bearing selected is used to calculate bearing seat elevations. The actual bearing supplied by the contractor must meet the requirements shown on the plans and be listed on the Ministry's approved sources for the appropriate class of bearing.

BEARING PERFORMANCE

Figures 1 to 4 illustrate problems which have occurred with sliding plates, rockers, and rollers. The deficiencies reported are by no means unique to Ontario and have been documented in many other jurisdictions (8,9,10).

Figure 1 illustrates a typical steel-on-steel sliding plate on an old truss bridge after dirt had been removed so that the bearing was visible in the photograph. The accumulation of debris around the sliding surface and in the slotted anchor bolt hole is clearly visible. This type of bearing is also vulnerable to misalignment and bent, sheared, or corroded anchor bolts. Because such bearings cannot accommodate rotation, pressures are usually non-uniform.

Figure 2 shows a rocker in which the retainer plate is broken as a result of unanticipated lateral movement of the bridge.

Bearings of this type were once commonly used on short span structures, but have the serious limitations of a small movement range and the stress distribution on the bearing is often non-uniform since they provide rotational capacity about only one axis and debris (especially sand and small stones) often become lodged in the rocking surface. Figure 3 illustrates an extreme example of the performance of a rocker where, because of excessive tilt, the bearing is in danger of imminent collapse.

Figure 4 shows a twin roller nest which exhibits the deficiencies of corrosion, flattened rollers and the pins holding the coupling plate being installed off center. This site is a good illustration of the superficial inspection and maintenance of bearings which are all too common. The roller skirts were in good condition and had been repainted frequently, but it is doubtful that the rollers themselves had been inspected since the bridge was constructed.

Observations have shown that skirts around rollers and rockers have been effective in keeping debris away from the moving surfaces and in reducing corrosion damage. These observations led to consideration of encapsulating the bearing in a waterproof cocoon as a means of preventing corrosion. Figure 5 illustrates a rocker bearing which was installed in 1967 and encapsulated in a rubber sleeve. The seam in the sleeve was vulcanized and the contact surfaces between the sleeve and the bearing were caulked and strapped. When the sleeves were removed for inspection in 1985, the sleeves and caulking appeared to be watertight. However, there was condensation on the inside of the sleeve and significant corrosion of the rocker, as shown in Figure 6, indicating that this is not an effective means of corrosion protection.

Since their first use in Ontario in 1957, unconfined elastomeric bearings have given good performance. In fact, there has been only one case of elastomeric bearings which have been replaced because of failure in service. In that case the laminates separated. This does not mean that such bearings are free from defects. A small number of bearings exhibit surface crazing which has been attributed to insufficient anti-oxidants in the elastomeric compound. During a period in the late 1960's and early 1970's the Ministry permitted laminated bearings to be cut from a large molded slab and a 3 mm thick cover was bonded to the edges to protect the steel plates. It was found that the cover cracked and exposed the plates to corrosion. It is not known how far the corrosion will progress into the bearing and although none of these bearings has been replaced, their service life is uncertain.

As with all other bearings, elastomeric bearings are subject to prequalification testing and there have been numerous failures at this stage of approval. Failure to meet the requirements for bond between the laminates has been the most frequent cause for rejection. Misalignment of the plates is also common, and

occasionally the elastomer has failed to meet the requirements for tensile strength and hardness. Bearings are also sampled at the job site for quality assurance testing. Failures, with again bond being the most common, have also occurred at this stage. In fact, there have been so many failures during approval and quality assurance testing that there can be little confidence that bearings not meeting specification requirements have not been installed in highway bridges. Nevertheless, the performance record remains almost unblemished.

An interesting and somewhat surprising aspect of the performance of steel-laminated, natural rubber, elastomeric bearings was recorded following the fire of a gasoline tanker directly beneath a post-tensioned concrete structure west of Toronto in March, 1986. The fire burned for 2 1/2 hours and the structure was so badly damaged that it had to be demolished. Although the temperatures reached are not known, the heat was sufficient to spall concrete adjacent to the bearings. However, the bearings showed no visible evidence of damage.

The load and movement capacity of elastomeric bearings is limited and pot, spherical, or disc bearings must be used in large span structures. These bearings are much more complex than those discussed above and consequently the modes of possible failure are more numerous. Several types of deficiency and failure have been experienced and these are summarized in Table 1. The table describes the defect encountered, the possible causes, the action taken and, where appropriate, illustrates the defect. In most cases, the action taken has been a clause in the Ministry's specification which is intended to prevent a future occurrence of the problem.

The natural rubber disc shown in Figures 13 and 14 was tested for several physical properties to determine whether the poor performance was the result of an inferior disc. The results are given in Table 2. The TFE element shown in Figure 13, together with the elements removed from three other bearings were also subjected to physical testing. The results are given in Table 3. Although two of the TFE elements had borderline tensile strength, there was no indication that poor performance could be attributed to poor quality materials. Since the specification requirements are generally interpreted as being representative of high quality TFE and natural rubber, the implication is that the choice of materials was inappropriate or, more likely, the design and/or fabrication of the bearing was deficient.

ACCEPTANCE OF BEARINGS

The Ministry uses a system of prequalifying most products used in bridge construction. In general terms, the manufacturer must supply evidence that the product meets the Ministry's specification requirements. Design and construction details which are not specifically addressed in the specifications are evaluated

in the Ministry's laboratories and acceptance is based largely on engineering judgement.

Such a system has been in effect for bearings since the introduction of unconfined elastomeric bearings and has proven to be quite successful in satisfying the diverse needs of the agency, the contractor, the bearing supplier and the bearing manufacturer. However, it must be recognized that the design of unconfined elastomeric bearings to satisfy a particular specification is a fairly standard procedure and that most of the differences in bearings from different suppliers can be attributed to the quality of manufacture. However, pot, sliding and disc bearings usually contain proprietary details and the agency is faced with the problem of how to accept bearings from different manufacturers intended to provide equal performance but which may be quite different in form and materials. Furthermore, the procedure should result in the equitable treatment of manufacturers and create an environment in which there is an incentive for product improvement.

A well written performance specification accompanied by a strong manufacturer's guarantee would be the ideal solution, but it has proved to be an elusive goal. A performance specification would, in theory at least, satisfy the agency's requirement of having a bearing suitable for the intended purpose. Such an approach correctly places the responsibility for bearing design and product development on the bearing manufacturer. It also protects the interests of the agency while encouraging innovation by the manufacturer. This aspect is important because one of the major weaknesses of using prescription specifications and standard details is that there is rarely a commitment to periodic review and updating. Current bearing specifications, including the Ministry's latest specifications (6,7) contain performance requirements with respect to load, movements, replaceability and installation. It has not been possible to write true performance specifications because a number of important requirements such as those for durability are difficult to quantify. Another important factor is that specifications are often the method by which an agency protects itself against a repetition of earlier unsatisfactory experiences. This is the case with the Ministry's specifications where many of the clauses were written specifically to avoid the performance problems identified in the previous section.

The second component of the ideal acceptance procedure, the manufacturer's guarantee, has also been found to be unworkable. On most contracts there are a minimum of three parties involved with the bearings: the agency, the contractor, and the bearing manufacturer. Sometimes, there is also the bearing supplier since a number of manufacturers do not market their products directly to contractors. Under these conditions, it is often difficult to establish responsibility for unsatisfactory performance of bearings. The performance of the bearing is

determined by the articulation of the total bridge structure which is calculated by the agency's designer and over which the contractor has no control. The bearing supplier and manufacturer will not accept responsibility since the contractor is responsible for installation. Procedures such as requiring the manufacturer's or supplier's representative to certify the bearing installation are expensive and place the supplier or manufacturer in a position of authority but without control and in which he is vulnerable to financial pressure from the contractor if the certificate is withheld. Consequently, any attempt to ensure satisfactory performance through the use of a performance guarantee is fraught with administrative and legal difficulties. It is therefore, not surprising that specifications are a mix of performance and prescription requirements and the agency acceptance procedures are much more comprehensive than if a performance guarantee were used.

In the case of the system in use in Ontario, the first step in the acceptance procedure for rotational and sliding bearings is the submission of typical drawings for each class and type of bearing. The three classes of bearings are pot, disc, and spherical bearings. Within each class there are fixed, uni-directional and multi-directional types, each with and without provision for uplift, giving a total of six types. The drawings are checked for compliance with the requirements of the specification and, once these have been checked, the manufacturer submits the design calculations and shop drawings, followed later by a sample of the smallest, uni-directional bearing in each class for which approval is desired. The manufacturer's name is then added to the Ministry's designated sources list which must be used by all contractors. Before bearings are manufactured for a particular contract, shop drawings must be approved. The shop drawings must be accompanied by a copy of the approved typical drawing since this aids municipalities and their consultants who use Ministry specifications in identifying any differences from the approved details. The Ministry retains the right to inspect bearings during fabrication. Samples may be removed from the job site prior to installation for non-destructive testing which largely consists of a dimensional check and visual inspection for conformance with the shop drawings. Occasionally, the contract will require the supply of additional bearings for destructive testing and these are selected at random at the job site.

Under this system, the contractor is held responsible for defects in materials, workmanship and installation. Responsibility for materials and workmanship are passed along to the supplier or manufacturer as the case may be. Installation is checked by the Ministry's staff on site and, once accepted, the contractor has no further responsibility for the bearing. In effect, a performance guarantee has been replaced by a rigid system of prequalification and inspection. Despite the several steps involved, the procedure works reasonably well and can be expected to continue until performance standards and acceptance

criteria can be defined adequately. While it may appear to place an undue degree of responsibility on the agency, it must be remembered that if a performance guarantee were required, the difficulties of enforcement, the cost of the guarantee to the contractor, the indirect costs such as traffic control during repairs, and the repercussions resulting from inconvenience to the public, are ultimately borne by the agency.

CONCLUSIONS

The paper describes the effects of design, manufacture, and installation of bearings on their performance in highway structures. Particular emphasis is placed on proprietary rotational and sliding bearings and the specification requirements which have been implemented to try and prevent similar experiences in the future. The more significant developments are as follows:

1. The severity of the highway bridge environment for mechanical components such as bearings has been recognized and addressed through three complementary approaches:

   i) The structure is designed to have the minimum number of bearings consistent with the requirements for articulation.

   ii) A high degree of corrosion protection is specified.

   iii) Bearings must be replaceable without damage to the structure. Jacking points must be provided.

2. All bearings must have a rotational capacity about all three axes. This requirement eliminates the use of rockers, rollers, sliding plates, and cylindrical bearings.

3. A performance guarantee, though desirable, is not yet practical.

REFERENCES

1. "Standard Specifications for Highway Bridges", American Association of State Highway and Transportation Officials, Twelfth edition (1977).

2. "Ontario Highway Bridge Design Code". Ontario Ministry of Transportation and Communications, First edition (1979).

3. Dorton, R.A., and Csagoly, P.F., "The Development of the Ontario Bridge Code", Ontario Ministry of Transportation and Communications (1977), 67pp.

4. "Ontario Highway Bridge Design Code", Ontario Ministry of Transportation and Communications, Second edition (1983).

5. BS5400, "Steel, Concrete and Composite Bridges, Part 9 Bridge Bearings", British Standards Institution (1983).

6. OPSS 1203, "Material Specification for Bearings - Rotational and Sliding Surface", Ontario Ministry of Transportation and Communications (1986).

7. OPSS 922, "Construction Specification for the Installation of Bearings", Ontario Ministry of Transportation and Communications (1986).

8. Lee, D.J., "The Theory and Practice of Bearings and Expansion Joints for Bridges", Cement and Concrete Association, U.K. (1971), 65pp.

9. "Bridge Bearings", NCHRP Synthesis of Highway Practice No. 41, Transportation Research Board (1977), 62pp.

10. Lee, D.J., "Recent Experience in the Specification, Design Installation, and Maintenance of Bridge Bearings", Joint Sealing and Bearing Systems for Concrete Structures, ACI SP-70, Vol. 1 (1981), pp 161-175.

Table 1/ Summary of Deficiencies Observed in Pot Bearings and TFE Sliding Surfaces

Defect	Possible Causes	Action	Illustration
1. TFE deforming and squeezing out under cyclical movements.	. TFE not bonded and/or recessed to rigid backing material.	. TFE recessed into and bonded to rigid backing material. Backing material grit blasted to improve bond.	Figure 7 shows a pot bearing in which the TFE squeezed out in a series of cyclical movements. Figure 8 shows a less extreme example where the TFE has been squeezed out and has split.
	. Depth of recess inadequate. . Free height of TFE excessive. . TFE and/or stainless steel not flat.	. Depth of recess and free height of TFE specified. . Flatness of TFE and stainless steel specified.	
2. TFE on guide bars becoming loose.	. TFE not bonded adequately. . Countersunk screws used for mechanical fastening inadequate or rusted.	. Virgin TFE recessed and bonded. . Lead filled TFE bonded and mechanically fastened.	The TFE which has become detached from the guide bar is clearly visible in Figure 9.
3. TFE adhering to the stainless steel mating surface.	. Lack of lubrication. . Stainless steel not smooth enough.	. TFE dimpled and lubricated. . Roughness of mating surface specified.	Figure 10 shows an exploded view of a bearing which was replaced. Note the TFE fibers adhering to the stainless steel and the corrosion of the stainless steel.
4. Stainless steel sliding surface binding on TFE backing plate.	. TFE free height inadequate. . Tolerances on TFE or recess plan dimensions excessive.	. Thickness and free height of TFE specified. . Dimensional tolerances for TFE and recess specified.	In Figure 11, the stainless steel is bearing directly on the TFE backing plate except in the center of the bearing.

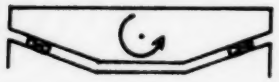
Defect	Possible Causes	Action	Illustration
5. Guides for lateral restraint broken.	. Base guided bearings allowing rotation about the transverse axis only and not permitting rotation about the longitudinal axis: a) the bearing seat not being perfectly level in the transverse direction b) unanticipated rotation of the superstructure about is longitudinal axis.	. Rotational capacity about <u>any</u> horizontal axis for <u>all</u> bearings specified as: maximum: as shown on the plans minimum: $\pm 0.5^{\circ}$.	
	. Translation accompanied by rotation of bearing in plan due to curvature of the superstructure. . Misalignment of bearing with guides in plan.	. Rotational capacity about the vertical axis through the center of the bearing for <u>all</u> bearings specified as: maximum: as shown on the plans minimum: $\pm 1^{\circ}$.	
	. Inadequate attachment of the guide bars to the top plate.	. Guide bars recessed 5 mm into backing plate and bolted.	In Figure 12, the superstructure has been displaced transversely and the guide bar fasteners broken. In Figure 13, the bearing was installed on an incline as shown in the sketch opposite. The base of the bearing has lifted on one side as a result of torsional movement of the bridge.
	. Use of two sloping bearings to resist torsion as shown below. 	. Prohibit use of sloping bearings to resist torsion.	

Table 1/ (Cont.) Summary of Deficiencies Observed in Pot Bearings and TFE Sliding Surfaces

Defect	Possible Causes	Action	Illustration
6. Excessive edge pressure on cylindrical bearings.	. Not perfectly level because of imperfect setting or unanticipated rotation in transverse direction. . Misalignment of bearing in plan.	. Cylindrical (and rocker) bearings no longer used because they cannot satisfy requirements for rotation about any horizontal axis and the vertical axis.	
7. Confined elastomeric disc damaged or squeezed out.	. No lubrication. . Excessive tolerances. . Inadequate seal.	. Pot and piston surfaces in contact with confined elastomer lubricated with silicone grease. . Tolerances specified. . Two snugly fitting brass sealing rings recessed in the perimeter of the top surface of the elastomer. . Vertical strain at edge of elastomer under maximum rotation limited to 0.15 of the elastomer thickness. . Roughness of metal surfaces in contact with confined elastomer specified.	Figure 14 shows an exploded view of the TFE element, piston, elastomer disc and sealing rings of a pot bearing. It should be noted that there was no external evidence of deficiencies in this bearing which was removed for inspection at the same time as an adjacent, defective bearing was being replaced. Figure 15 shows the amount of abrasion of the disc. The worn portion was present as a black powder inside the pot.

Table 1/ (Cont.) Summary of Deficiencies Observed in Pot Bearings and TFE Sliding Surfaces

Defect	Possible Causes	Action	Illustration
8. Corrosion of internal and external metal components.	. Inadequate corrosion protection. . Inadequate sealing between piston and pot. . Poor drainage around bearings.	. External surfaces required to have a zinc primer plus 3 coats of vinyl coating. . Steel fasteners galvanized. . Aluminum alloy surfaces anodized. . Contact between dissimilar metals and between aluminum alloy and concrete prevented by insulation. . Use of highly corrosion resistant stainless steel. . Pot bearings sealed against entry of dirt, dust and moisture by a continuous, preformed, closed cell compressible ring. . Internal surfaces of pot and piston lubricated. . Design details require sealed deck joints and sloping bearing seats.	Figure 13 shows extensive corrosion of the brass sealing rings and the top surface of the piston to which the TFE element was attached. Figure 11 shows corrosion of a metallized spherical bearing within two years of installation. Note that the rust staining is the result of corrosion of the bearing, not staining from the girder.
9. Piston slipping out of pot.	. Pot too shallow.	. Depth of pot wall required to be a minimum 2.5 mm higher than the closest point of contact of the sealing rings under required rotation plus 1^{o}.	
	. Excessive tolerances. . Possibility of (accidential or intentional) disassembly during erection.	. Tolerances specified. . Disassembly not permitted.	

Table 1/ (Cont.) Summary of Deficiencies Observed in Pot Bearings and TFE Sliding Surfaces

Defect	Possible Causes	Action	Illustration
10. Stainless steel slipping out and/or crevice corrosion between the stainless steel and the backing plate.	. Countersunk fasteners used to attach thin stainless steel plate either inadequate or corroded. . Stitch welding.	. Stainless steel thickness specified as a function of the dimensional difference between the stainless steel and TFE. . Stainless steel continuously welded around the perimeter.	Separation of the stainless steel from the backing plate is visible in Figures 9 and 12.
11. Difficult to replace bearings without removal of welds and/or removal of concrete and/or provision of extensive falsework.	. Poor anchorage details.	. Entire bearing assembly (except top and bottom plates used for attachment to superstructure and substructure) to be replaceable without removal of any welds, concrete or anchors and without lifting the superstructure more than 5 mm.	
	. Jacking points not provided. . Insufficient space for jacks.	. Jacking points provided with a minimum vertical space for jacks of 150 mm.	

Table 2/ Physical Properties of Natural Rubber Disc

Property	Test Method	Test Result	Specification Requirement
Tensile Strength, MPa	D412	19.3	17.6
Elongation, %	D412	400	400
Hardness, ° Shore A	D2240	54	55±5
Heat Resistance, 70 hr at 70°C	D573		
Change in Tensile Strength, %		-0.3	max. -25
Change in Elongation, %		2.5	max. 25
Hardness, ° Shore A		1	max. +10
Compression Set, %	D395 Method B	12.9	max. +25
Low Temperature Stiffing, ° Shore A	D2240	0	max. +15

Table 3/ Physical Properties of TFE Elements

Property	Test Method	Bearing A	B	C	D	Requirement
Tensile Strength, MPa	D638	19.2	20.8	19.3	20.2	min. 20
Elongation, %	D638	330	270	290	260	min. 200
Relative Density	D792	2.18	2.14	2.15	2.15	2.16 ± 0.03

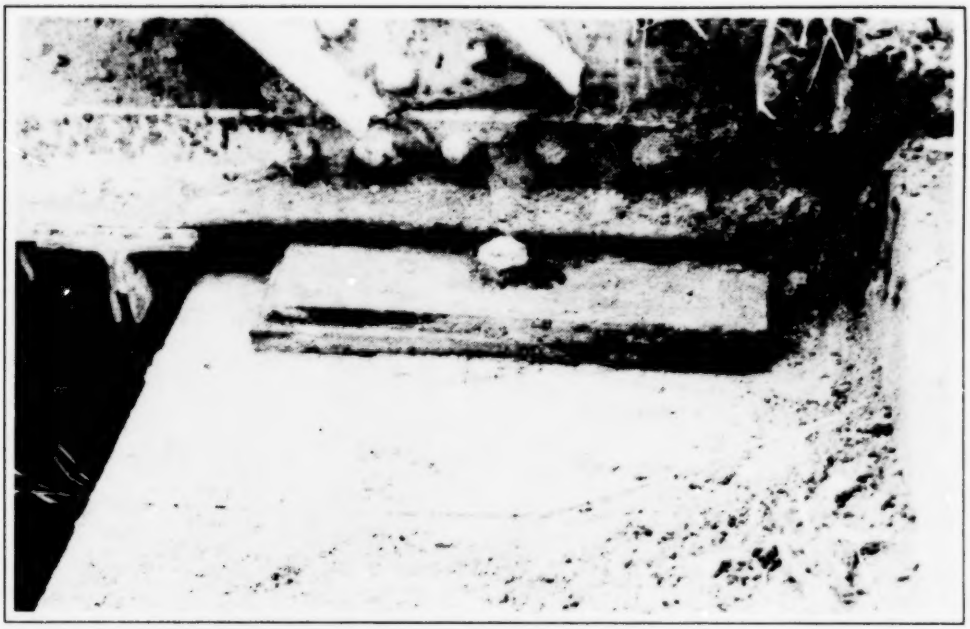


Figure 1/ Site 32-008, Dartmoor Bridge, Conc. 2, Dalton Twp., Victoria County

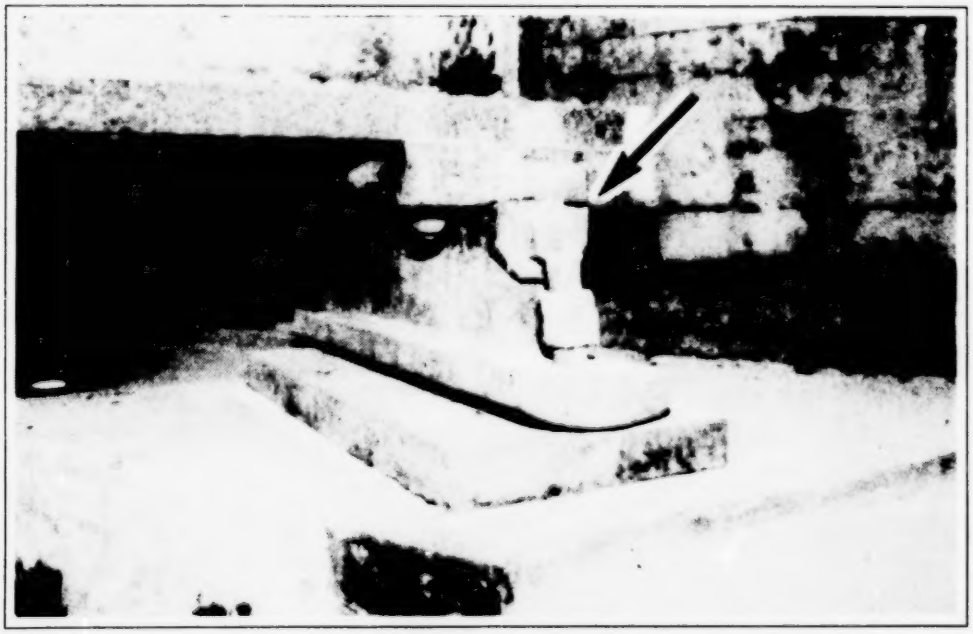


Figure 2/ Site 03-042, Maitland Avenue U.P., Hwy 417

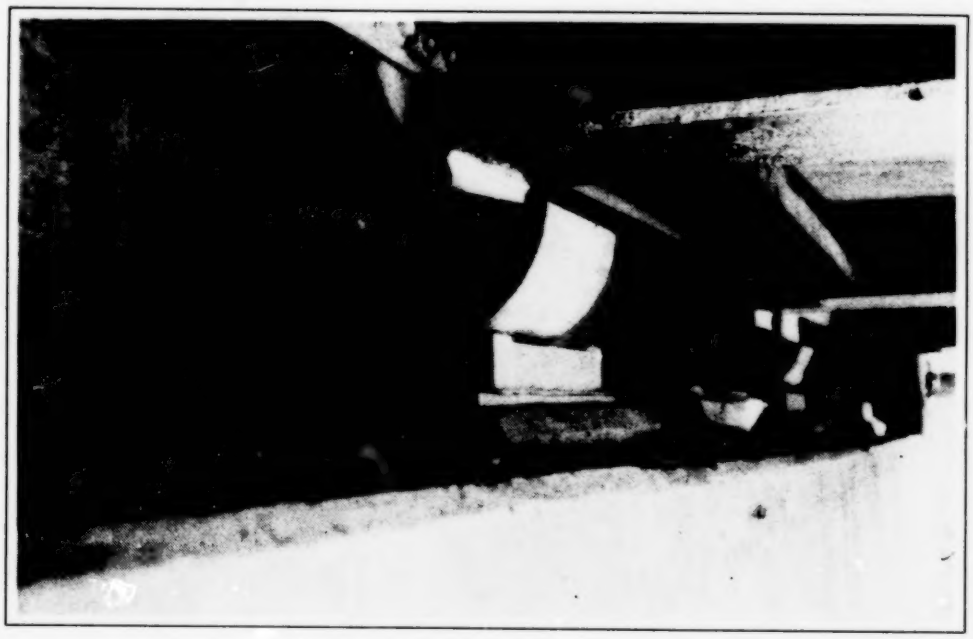


Figure 3/ Site 29-172, Portage du Fort Interprovincial Bridge, Hwy 653

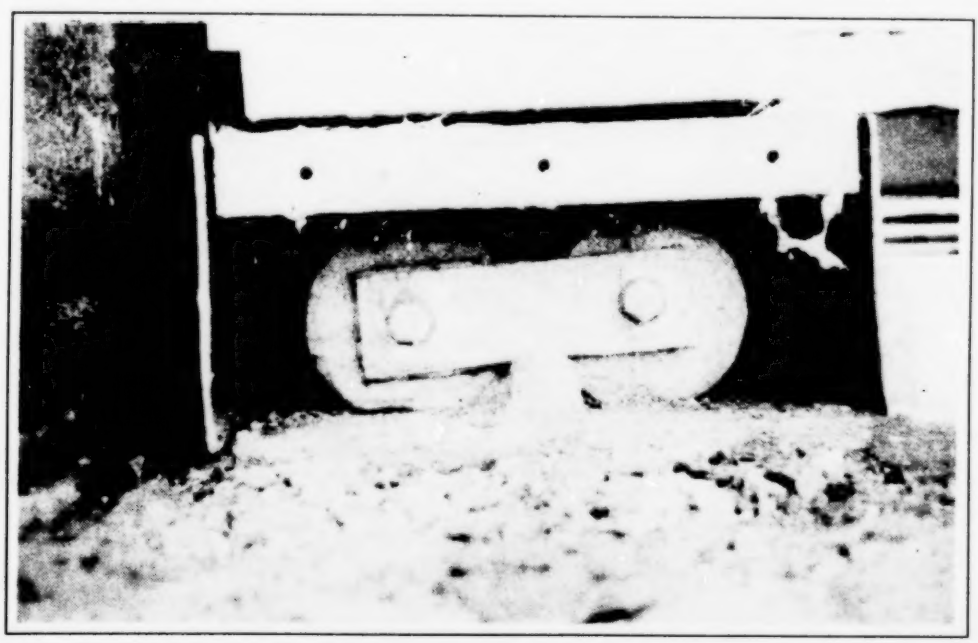


Figure 4/ Site 15-064, Mississippi River Bridge, Hwy 7

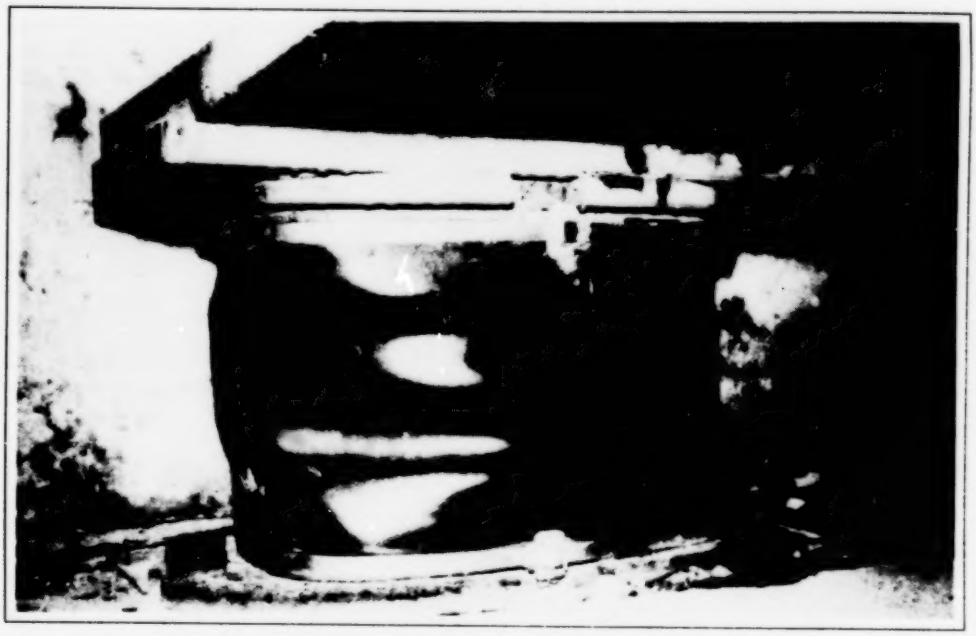


Figure 5/ Site 11-239, Trent River Bridge, Trenton

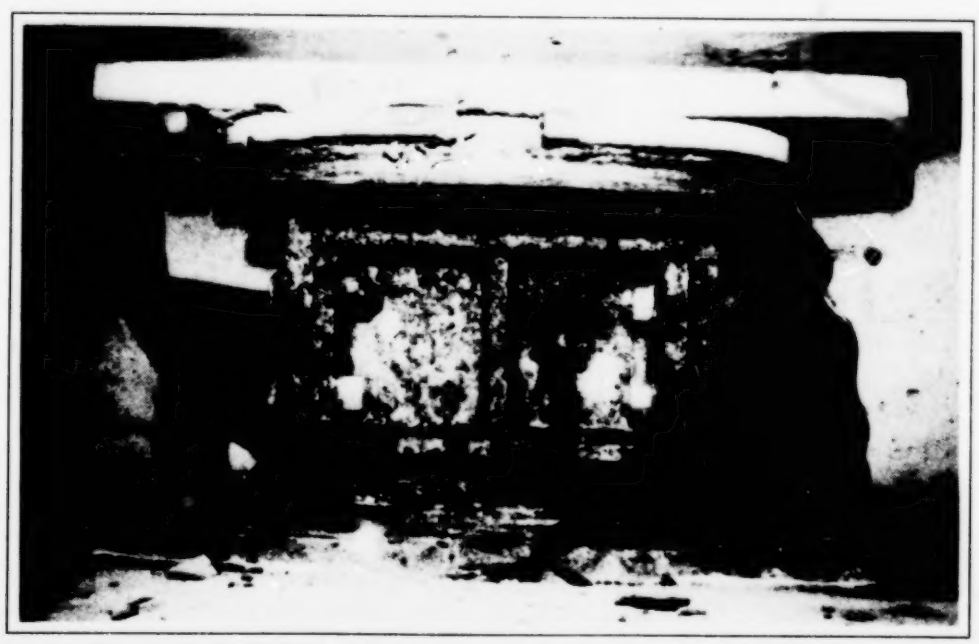


Figure 6/ Site 11-239, Trent River Bridge, Trenton

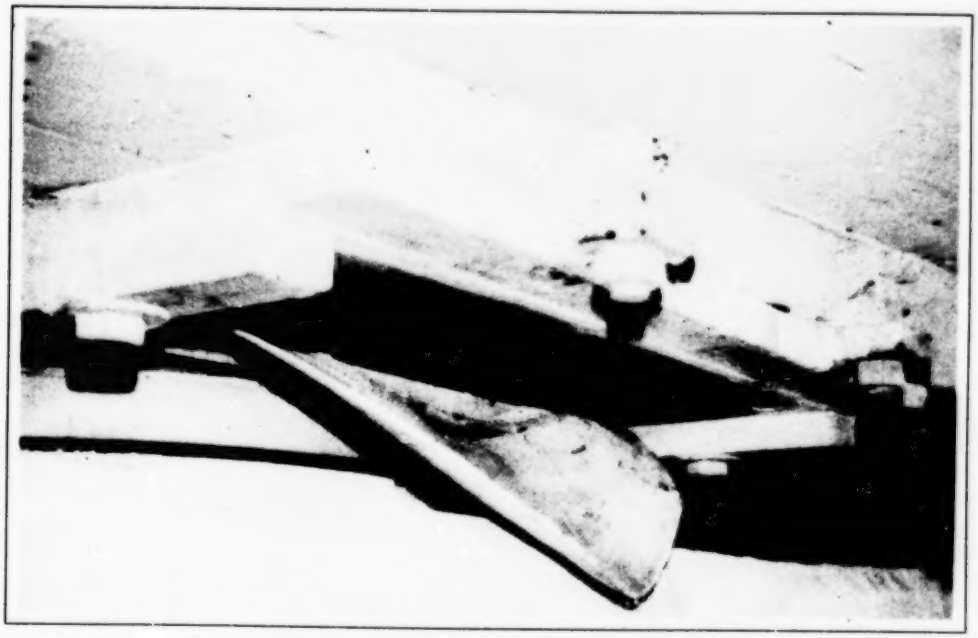


Figure 7/ Site 03-270, Boundary Road U.P., Hwy 417

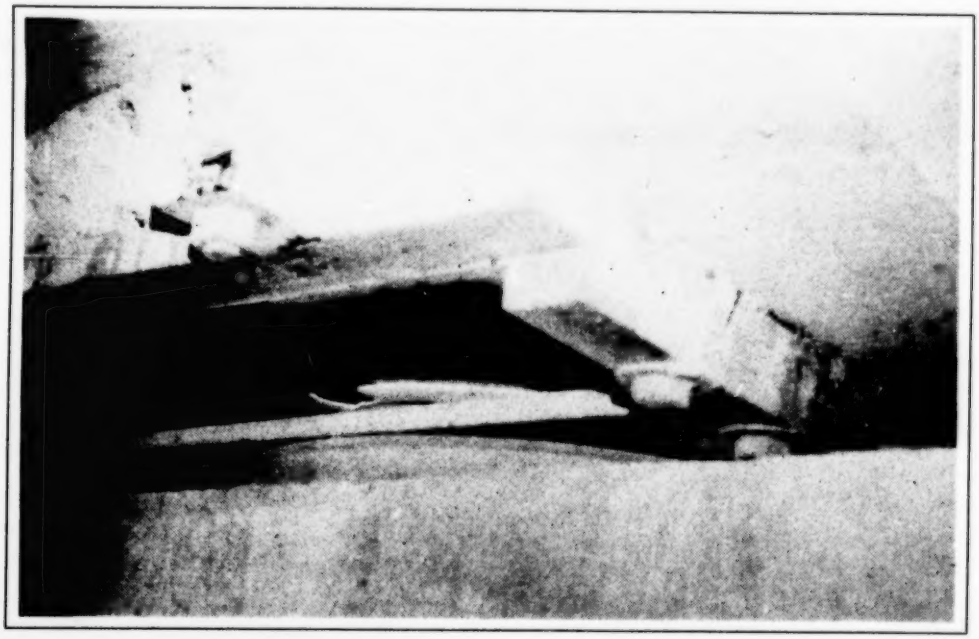


Figure 8/ Site 03-303, Eastbound O.P., Hwys QEW/417 I.C.

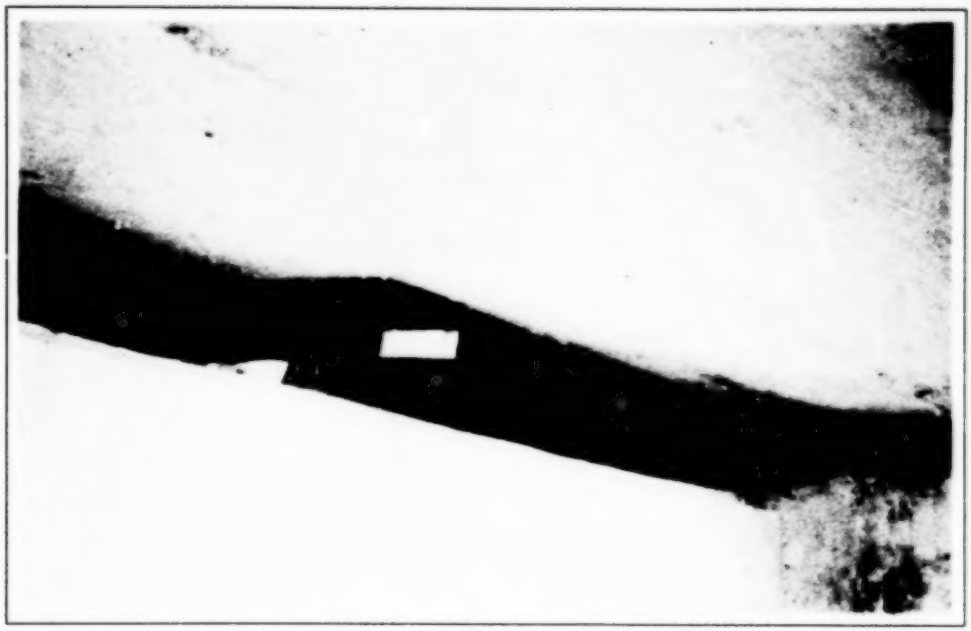


Figure 9/ Site 37-812, Bridge No. 27, Hwys 401/27 I.C.

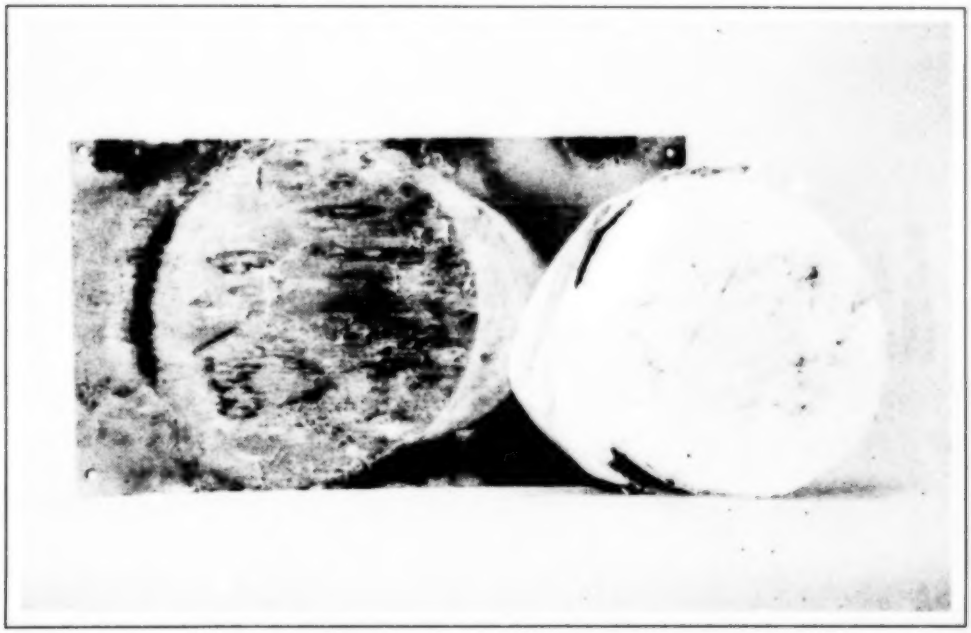


Figure 10/ Site 03-263, Seventh Line U.P., Hwy 417

Figure 11/ Site 28-028, Norris Whitney Bridge, Hwy 62

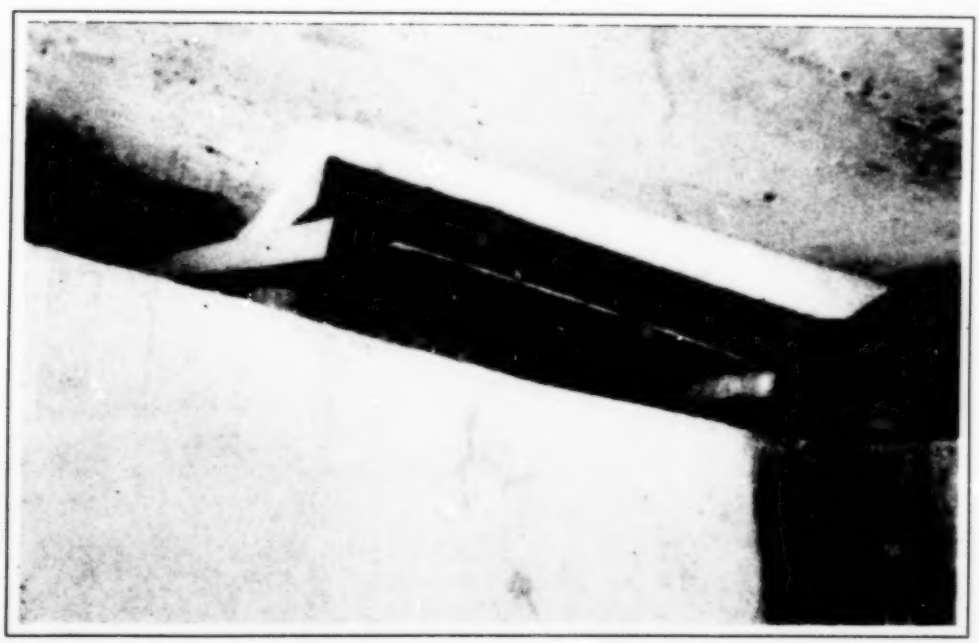


Figure 12/ Site 37-812, Bridge No. 27, Hwys 401/27 I.C.

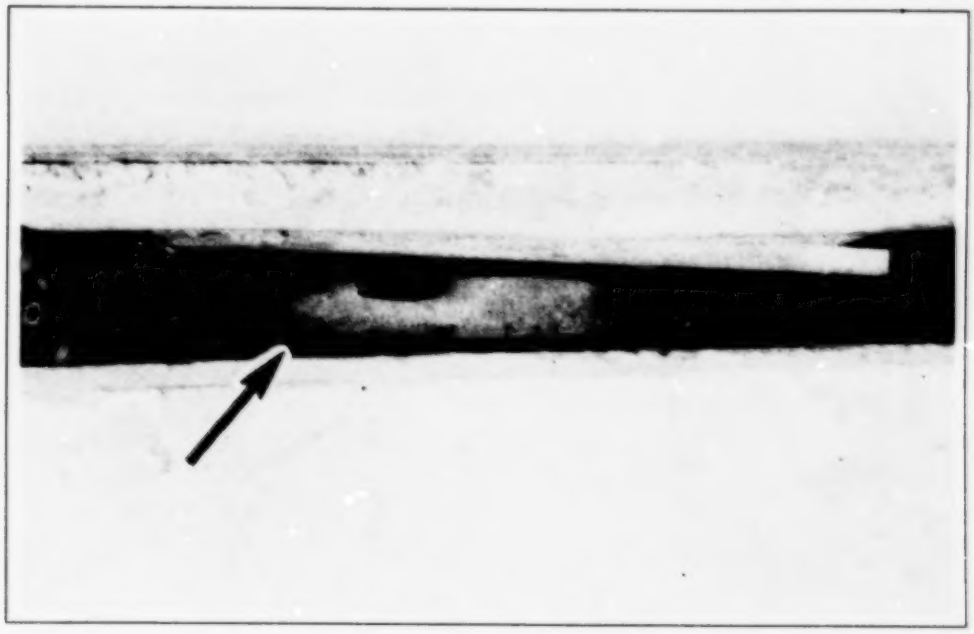


Figure 13/ Site 27-207, Vars Road U.P., Hwy 417

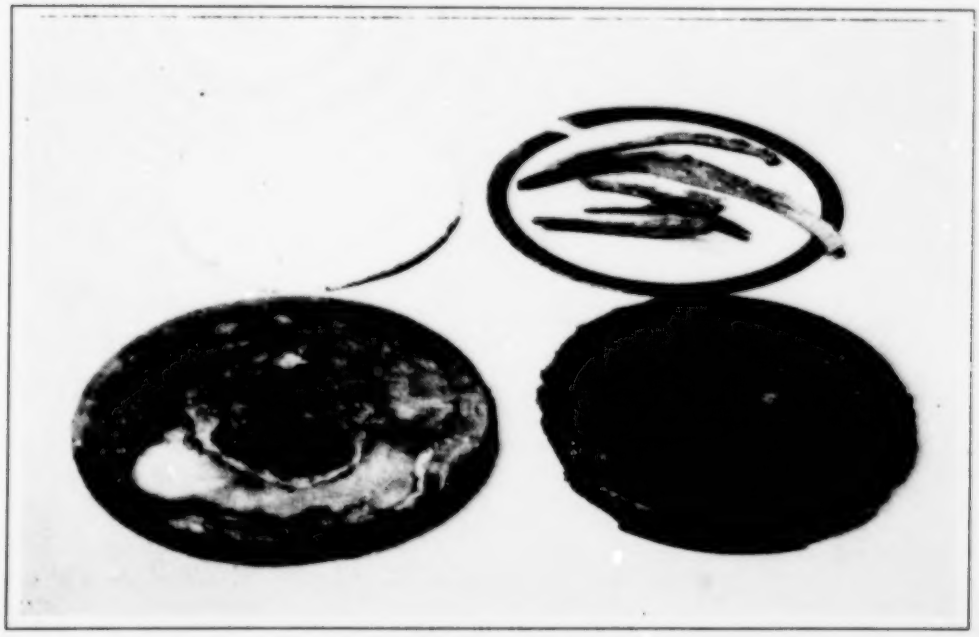


Figure 14/ Site 27-210, South Nation River Bridge, Hwy 417

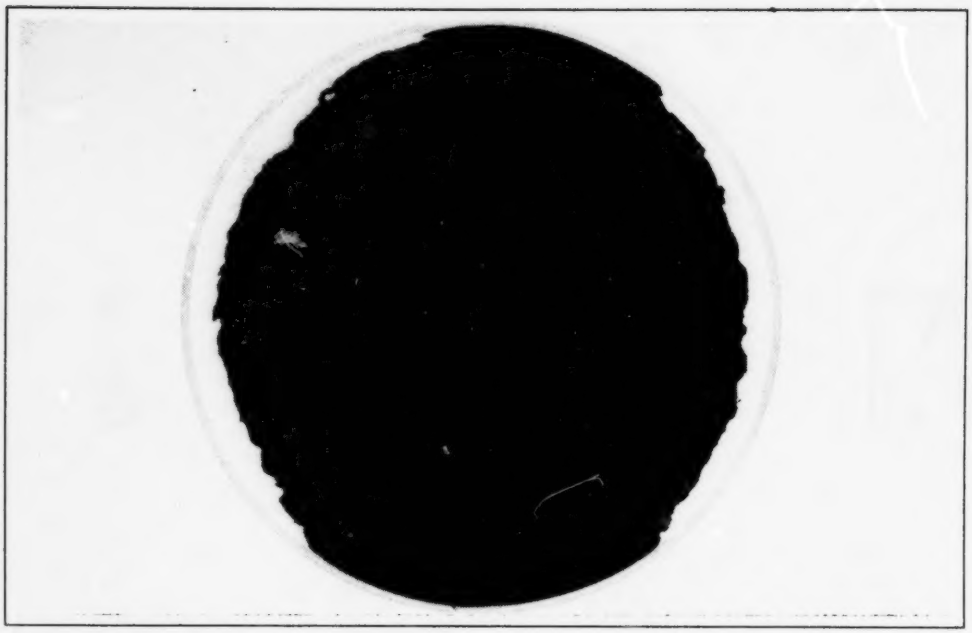


Figure 15/ Site 27-210, South Nation River Bridge, Hwy 417